SSME ALTERNATE TURBOPUMP DEVELOPMENT PROGRAM

DESIGN VERIFICATION TEST PLAN
HPFTP AND HPOTP WATER FLOW MODELS
DVS 29 DR NO. 3.1.2.2.6.1, VM NO. 4.1.3.2.1.1 B
DVS 30 DR NO. 3.1.2.2.5.1, VM NO. 4.1.3.2.1.1 B

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UNITED TECHNOLOGIES
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(NASA-CR-183765) SSME ALTERNATE TURBOPUMP DEVELOPMENT PROGRAM. DESIGN VERIFICATION TEST PLAN: HPFTP AND HPOTP WATER FLOW MODELS DVS 29 DR NO. 3.1.2.2.6.1, VM NO. 4.1.3.2.1.1. B, DVS 30 DR NO .3.1.2.2.5.1, 00/20

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INTERNAL CORRESPONDENCE

To: J.L. Price
From: V. Garcia
Subject: ATD Inlet Flow Model Test Plan
Date: February 19, 1987
Copy To: C.D. Andrews (MSFC), W.J. Bordelon (MSFC), G.L. Clark, G.B. Cox, C.C. Dill (MSFC), G.H. Duncan, D.L. Elmore, J.F. Gearhart, H.M. Gibson, H.S. Gwinn (MSFC), J.P. Heaman (MSFC), O.E. Hill (MSFC), W.B. Lunn, J. Pearson, P.E. Ramsey (MSFC), M.T. Reher, F. Tate

The testing of the ATD Inlet Flow models will verify the design of the Turbopump inlet flow path and impeller/inducer. Included herein is an outline of the objectives and requirements for these tests followed by a description of the configurations to be tested and the measurement/observation techniques to be implemented. In addition, a detailed test procedure is attached (Refer to FIGURE 4 for valve locations).

OBJECTIVES

1. Verify the absence of separated flow within the HPFTP and HPOTP inlet scrolls.

2. Verify low inlet losses and distortion into the inducer/impeller.

3. Identify optimal vane configuration of the two vane sets to be tested for the HPFTP.

4. Identify optimal configuration and angle of attack for HPOTP inlet vanes.

5. Confirm the absence of separation or flow distortion at the leading edge of inlet vanes.

6. Define loss coefficients and loss distributions thru the HPFTP and HPOTP Inlets.

7. Measure flow angle at the leading edge of inlet vanes and impeller/inducer leading edge for HPFTP and HPOTP.

8. Verify HPOTP and HPFTP inlet guide vane flow wakes do not adversely affect inducer/impeller.

9. Verify HPFTP impeller and HPOTP inducer suction performance.

10. Measure inducer/impeller tolerance to head fall-off and cavitation to verify adequate design margins.

11. Verify HPOTP inducer achieves adequate pressure rise during cavitation to meet impeller suction requirement.

REQUIREMENTS

Fabrication and testing of the ATD Inlet Flow Models is currently in progress; the schedule for this effort is shown in Figure 1. Prior to the commencement of testing the schedule shows a month's time allotted for stand modifications. These modifications are necessary to the performance of the four different tests scheduled, since the flow models not only require interfacing with the facility at different points than those currently existing, but in addition require unique interfaces within all the tests. These tests will consist of the simulation of the HPFTP and HPOTP inlets in both externally induced flow (forced thru model by external pump) models and self induced flow ("full scale" inducer/impeller internal to model forces flow) models. These self induced tests will require the use of two electric motors, a 125 Hp motor for the HPFTP model and a 50 Hp motor for the HPOTP. Testing will require water flow conditions as specified in the test procedures. Observations during this test will involve a combination of flow visualization, pressure measurements and flow direction (angle) measurements.

CONFIGURATION

The key feature of the HPFTP Inlet Flow Model is the inlet volute. The flow passage within the volute is identical to the ATD configuration. Flow from the volute is redirected by a set of inlet guide vanes into the impeller; two different sets of vanes will be tested to obtain the optimal configuration. Once a baseline configuration is defined a shrouded impeller will be incorporated into the model. This impeller differs from the actual pump version only by its smaller discharge diameter to reduce power requirements. The impeller is driven thru a shaft mounted on two bearings positioned external to the model. A belt drive system will provide power from the 125 Hp motor to the shaft.

Like the HPFTP model the main feature of the HPOTP Inlet Flow Model is the inlet flow passage; inlet guide vanes will also be used to redirect flow into the inducer face. To obtain an optimal inlet guide vane configuration this model will test a baseline configuration followed by two alternate configurations if necessary. In addition these vanes will have an adjustment feature to allow the variation of the vane angle of attack. Once the optimal configuration is obtained an inducer will be placed inside the model and driven with a system similar to that of the HPFTP model.

INSTRUMENTATION

To quantify the flow phenomena observed in the ATD Inlet Flow Models, a variety of probes and ports will be used. The types of measurements to be obtained are as follows:

- Static Pressure
- Total Pressure

- Static Pressure Differentials
- Total Pressure Differentials
- Flow Angles

Tables 1 and 2 provide a list of the headers, probe types, locations and ranges for the HPFTP model and the HPOTP model, respectively. In addition, on-line calculations to be executed are shown in Tables 3 and 4. The locations of these probes are also indicated in Figures 2 and 3. (Tables, Figure 2 and Figure 3 provided by G.L. Clark.)

There is a number of specialized probes implemented in both models; these probes are described below.

Total Pressure Kiel Probes

Total pressure kiel probes are used at three locations. These probes are located at the inlet to the model, at the leading edge of selected inlet guide vanes, and for the self induced tests at the impeller/inducer discharge. The total pressure probes at the model inlets can be rotated 45 degrees, for both HPFTP and HPOTP models, to obtain a complete profile of the flow exiting the SSME fuel or oxidizer supply ducts.

Wedge Probes

Wedge probes will be located slightly forward of the inlet guide vane leading edges between selected vane positions and will be removed when not in use. The wedge probes will provide the inlet volute discharge angle to verify inlet guide vane angle of attack as well as total pressures to define flow profiles.

Cobra Probes

Like the wedge probes the Cobras will be used to measure flow angle and total pressure. These instruments will be located in close proximity to the impeller/inducer inlet plane during the externally induced tests, hence these probes will be removed prior to the installment of any rotating hardware. Although wedge probes are a more accurate flow angle measurement instrument they require rotation capability and can not be accommodated in this location; angle is measured using the curves obtained from probe calibration. Calibration of the cobra probes to be used in these tests will be performed at MSFC as shown on the schedule.

FLOW VISUALIZATION

The visual observation of flow within the ATD Inlet Flow Models is one of the primary goals of these tests. These models will be fabricated of transparent acrylic plastics to facilitate this type of observation. Flow visualization is of major interest in several critical areas through the flow path. These areas are the inlet volute just past the Space Shuttle fuel and LOX supply duct interface, the leading edge of the pump inlet guide vanes, and the impeller/inducer leading edge. Flow visualization will verify the absence of separation and flow distortion in both the volute and the vanes; it will also assist in the understanding of cavitation in this configuration when this phenomena is forced by throttling the flow upstream.

These phenomena will be observed using two methods; air bubble injection and aluminum particle suspension. The first method will require the injection of small bubbles into the flow stream by pumping air through selected instrumentation probes and observing these bubbles as they travel with the stream. Both high speed photography and strobe light illumination will aid in defining flow profiles using this technique. During the self induced tests, strobe light illumination will also be used to observe cavitation at the leading edge of the impeller (fuel) and through the inducer (LOX). Cavitation will be induced at off design flow conditions to allow the observation of both suction and pressure side separation. The second method will introduce aluminum particles into the model water supply tank. These particles will be illuminated, using a LASER light source, as they pass through the model and thus reveal the flow characteristics.

Vicente Garcia

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INLET FLOW MODEL TEST PROCEDURE

I. HPFTP Externally Induced Flow Tests

A. Baseline test.

1. Obtain ambient dry reading.

2. Open valves V-230, V-240 and V-250 to max position.

3. Open valve V-210 slowly to max position. and allow system to flood. Continue to flow until water is observed dumping into catch tank.

4. Close valve V-250.

5. Bleed air from instrumentation lines until completely water flooded.

6. Record water off zero (reference).

7. Record pre-run static.

8. Slowly open valve V-250 to max position.

9. When steady state flow is reached obtain data reading.

Note

Adjust valve V-230 to regulate supply pump operating conditions (Q,N).

Caution

Throttle off excess inlet pressure with valve V-240 (35 psia, max.).

10. Start supply pump and raise flow slowly so as to allow close monitoring of flow rates and pressures until flow reaches 650 GPM.

11. Record pressure data.

12. Raise flow rate to 975 GPM; monitor all parameters closely.

13. Record pressure data.

14. Raise flow rate to 1300 GPM; monitor all parameters closely.

15. Record pressure data.

16. Slowly reduce pump speed until shut-off.

17. Close valve V-250.

18. Record post-run static.

19. Close valve V-210.

20. Purge system.

B. Wedge probe measurements.

1. Insert and attach wedge probe at position #1.
2. Repeat procedure for Baseline Test, steps 2 thru 15.
3. Verify null signal on wedge probe.
4. Record angle from indicator.
5. Record wedge probe total pressure.
6. Complete steps 16 through 20 of Baseline Test.
7. Insert and attach wedge probe at position #2.
8. Repeat steps 2 through 6 above.
9. Insert and attach wedge probe at position #3.
10. Repeat steps 2 through 6 above.
11. Rotate inlet kiel probes 45 degrees.
12. Rotate cobra probes 45 degrees.
13. Insert and attach wedge probe at position #4.
14. Repeat steps 2 through 6 above.
15. Insert and attach wedge probe at position #5.
16. Repeat steps 2 through 6.

C. Flow visualization.

1. Air ingestion.

   a. Insert air injection probes.

   b. Repeat steps 2 thru 15 of Baseline Test.

   c. Inject air bubbles forward of inlet guide vane leading edge.

   d. Traverse probe radially.

   e. Observe and record flow patterns along vane contour.

   f. Ingest air bubbles at various inlet flange kiel probe locations.

g. Observe and record flow patterns along inlet streamlines.

h. Complete steps 16 through 20 of Baseline Test.

i. Rotate inlet kiel probes 45 degrees.

j. Repeat steps b.,f.,g. and h. above.

2. Aluminum particle suspension.

a. Seed water supply tank with aluminum particles.

b. Repeat steps 2 through 15 of Baseline Test.

c. Illuminate.

d. Observe and record flow patterns.

e. Complete steps 16 through 20 of Baseline Test.

D. Inlet Duct distortion effects.

1. Install flow straightener internal to SSME fuel supply ducts forward of flow model interface.

2. Repeat air ingestion test procedure (Sect. I.C.1., at step i. also rotate cobra probes 45 degrees).

E. Alternate vane configuration.

1. Install alternate set of inlet guide vanes.

2. Repeat sections A., B., C., D.

II. HPOTP Externally Induced Flow Tests

A. Baseline Test.

1. Obtain ambient dry reading.

2. Open valves V-230, V-240, V-250 and V-270 to max position.

3. Open valve V-210 slowly to max position and allow system to flood. Continue to flow until water is observed dumping into catch tank.

4. Close valve V-250 and V-270.

5. Bleed air from instrumentation lines until completely water flooded.

6. Record water off zero (reference).

7. Record pre-run static.

8. Slowly open valve V-250 and V-270 to max position.

9. When steady state flow is reached obtain data reading.

Note

Adjust valve V-230 to regulate supply pump operating conditions (Q,N).

Caution

Throttle off excess inlet pressure with valve V-240 (35 psia, max.).

10. Start supply pump and raise flow slowly so as to allow close monitoring of flow rates and pressures until flow reaches 900 GPM.

11. Adjust valves V-250 and V-270 to obtain 450 GPM through each the bypass and model exit.

12. Record pressure data.

13. Raise flow rate to 1350 GPM; monitor all parameters closely.

14. Adjust valves V-250 and V-270 to obtain 675 GPM through each the bypass and model exit.

15. Record pressure data.

16. Raise flow rate to 1800 GPM; monitor all parameters closely.

17. Adjust valves V-250 and V-270 to obtain 900 GPM through each the bypass and model exit.

18. Record pressure data.

19. Slowly reduce pump speed until shut-off.

20. Close valve V-250 and V-270.

21. Record post-run static.

22. Close valve V-210.

23. Purge system.

B. Wedge probe measurements.

1. Insert and attach wedge probe at position #1.

2. Repeat procedure for Baseline Test, steps 2 thru 18.

3. Verify null signal on wedge probe.

4. Record angle from indicator.

5. Record wedge probe total pressure.

6. Complete steps 19 through 23 of Baseline Test.

7. Insert and attach wedge probe at position #2.

8. Repeat steps 2 through 6 above.

9. Rotate inlet kiel probes 45 degrees.

10. Rotate cobra probes 45 degrees.

11. Insert and attach wedge probe at position #3.

12. Repeat steps 2 through 6 above.

13. Insert and attach wedge probe at position #4.

14. Repeat steps 2 through 6 above.

C. Flow visualization.

1. Air ingestion.

a. Insert air injection probes.

b. Repeat steps 2 thru 18 of Baseline Test.

c. Inject air bubbles forward of inlet guide vane leading edge.

d. Traverse probe radially.

e. Observe and record flow patterns along vane contour.

f. Rotate vanes to minimize separation.

1) Observe flow to minimize separation.

2) Monitor pressures to reduce losses.

3) Record optimized position.

g. Record pressure data.

h. If flow distortion and losses have not improved or worsened return to step c. above.

i. Ingest air bubbles at various inlet flange kiel probe locations.

j. Observe and record flow patterns along inlet streamlines.

k. Complete steps 19 through 23 of Baseline Test.

l. Rotate inlet kiel probes 45 degrees.

m. Rotate cobra probes 45 degrees.

n. Repeat steps b.,g.,h.,i.,j. and k. above.

2. Aluminum particle suspension.

a. Seed water supply tank with aluminum particles.

b. Repeat steps 2 through 18 of Baseline Test.

c. Illuminate.

d. Observe and record flow patterns.

e. Complete steps 19 through 23 of baseline test.

D. Inlet Duct distortion effects.

1. Install flow straightener internal to SSME fuel supply ducts forward of flow model interface.

2. Repeat air ingestion test procedure (Sect. II.C.1).

E. Testing options.

1. Alternative vane configuration.

a. Install alternate set of inlet guide vanes (sets 2 and 3).

b. Repeat sections A., B., C., D.

2. Alternative inlet contour.

a. Install inlet contour inserts (sets 1 and 2).

b. Repeat sections A., B., C., D.

3. Inlet duct reverse orientation affects.

a. Rotate model 180 degrees about the vertical axis.

b. Repeat sections A., B., C., D.

III. HPOTP Self Induced Flow Tests.

A. Baseline Test.

1. Obtain ambient dry reading.

2. Open valves V-240, V-250, V-280 and V-290 to max position.

3. Open valve V-220 slowly to max position and allow system to flood. Continue to flow until water is observed dumping into catch tank.

4. Close valve V-250 and V-290.

5. Bleed air from instrumentation lines until completely water flooded.

6. Record water off zero (reference).

7. Record pre-run static.

8. Slowly open valve V-250 and V-290 to max position.

9. Adjust valves V-250 and V-290 to obtain equal flow through each the bypass and model exit.

10. When steady state flow is reached obtain data reading.

11. Start suction pump and model inducer drive. Control pump and model speeds per observed flows to maintain flow split evenly between bypass flow and internal flow. Increase model rotor speed to 2400 RPM.

12. Adjust valves V-250 and V-290 to obtain 360 GPM through each the bypass and model exit. Monitor all parameters closely.

13. Record pressure data.

14. Increase suction pump and model rotor speed. Adjust rotor speed to 3600 RPM, verify flow rate is 540 GPM through each the bypass and model exit. Monitor all parameters closely.

15. Adjust valves V-250 and V-290 if flow rate is not as specified.

16. Record pressure data.

17. Increase suction pump and model rotor speed. Adjust rotor speed to 4800 RPM, verify flow rate is 720 GPM through each the bypass and the model exit. Monitor all parameters closely.

18. Adjust valves V-250 and V-290 if flow rate is not as specified.

19. Record pressure data.

20. Note and record average inlet pressure (PTI Avg.).

21. Throttle back flow with valve V-240 until head rise thru the inducer begins to drop sharply.

22. Note and record average inlet pressure (PTI Avg.).

Note

When throttling back on valve to cause head rise fall-off it may be necessary to adjust valves V-250 and V-290 to even flow splits.

23. Reopen valve V-240 until previous average inlet pressure is regained.

24. Throttle back flow with valve V-240 in small increments of the ~~of the~~ difference in average inlet pressure noted in steps 20 and 22 note above and record pressure data at each increment.

25. Slowly reduce pump and rotor speed until shut-off.

26. Close valve V-250 and V-290.

27. Record post-run static.

28. Close valve V-220.

29. Purge system.

B. Off Design Suction Characteristic.

1. Repeat steps 2 through 24 of Baseline Test except reduce flow by 10 percent (325 GPM: step 12, 485 GPM: step 14, 650 GPM: step 17).

2. Reduce rotor speed to 2400 RPM.

3. Repeat steps 12 through 24 of Baseline Test except reduce flow by 20 percent (290 GPM: step 12, 430 GPM: step 14, 575 GPM: step 17).

4. Reduce rotor speed to 2400 RPM.

5. Repeat steps 12 through 24 of Baseline Test except increase flow by 10 percent (395 GPM: step 12, 595 GPM: step 14, 790 GPM: step 17).

6. Reduce rotor speed to 2400 RPM.

7. Repeat steps 12 through 24 of Baseline Test except increase flow by 20 percent (430 GPM: step 12, 650 GPM: step 14, 865 GPM: step 17).

8. Repeat steps 23 through 29 of Baseline test.

C. Cavitation

1. Repeat steps 2 through 19 of Baseline Test.

2. Throttle back flow with valve V-240 until head rise thru inducer begins to drop sharply and continue until cavitation is induced.

3. Record pressure data.

4. Illuminate inducer using strobe light and vary frequency until inducer rotation is visually eliminated.

5. Make record of observation.

6. Slowly continue to throttle back and allow cavitation to extend through the impeller until reaching the trailing edge; concurrently make record.

7. Record pressure data.

8. Reduce flow rate to 650 GPM through each the bypass and model exit by adjusting valves V-250 and V-290.

9. Repeat steps 2 through 7 above.

10. Reduce flow rate to 575 GPM through each the bypass and model exit by adjusting valves V-250 and V-290.

11. Repeat steps 2 through 7 above.

12. Reduce flow rate to 790 GPM through each the bypass and model exit by adjusting valves V-250 and V-290.

13. Repeat steps 2 through 7 above.

14. Reduce flow rate to 865 GPM through each the bypass and model exit by adjusting valves V-250 and V-290.

15. Repeat steps 2 through 7 above.

16. Repeat steps 25 through 29 of Baseline Test.

IV. HPFTP Self Induced Flow Tests

A. Baseline test.

1. Obtain ambient dry reading.

2. Open valves V-240, V-250 to max position.

3. Open valve V-220 slowly to max position and allow system to flood. Continue to flow until water is observed dumping into catch tank.

4. Close valve V-250.

5. Bleed air from instrumentation lines until completely water flooded.

6. Record water off zero (reference).

7. Record pre-run static.

8. Slowly open valve V-250 to max position.

9. When steady state flow is reached obtain data reading.

10. Start model impeller drive.

11. Increase model rotor speed to 1120 RPM.

12. Adjust valves V-250 to obtain 520 GPM flow. Monitor all parameters closely.

13. Record pressure data.

14. Increase model rotor speed to 1680. Monitor all parameters closely.

15. If flow rate is not 780 GPM adjust valve V-250.

16. Record pressure data.

17. Increase model rotor speed to 2240. Monitor all parameters closely.

18. If flow rate is not 1040 GPM adjust valve V-250.

19. Record pressure data.

20. Note and record average inlet pressure (PTI Avg.).

21. Throttle back flow with valve V-240 until head rise thru the impeller begins to drop sharply.

22. Note and record average inlet pressure (PTI Avg.).

23. Reopen valve V-240 until previous average inlet pressure is regained.

24. Throttle back flow with valve V-240 in small increments ~~of the~~ of the difference in average inlet pressure noted in steps 20 and 22 note above and record pressure data at each increment.

25. Slowly reduce rotor speed until shut-off.

26. Close valve V-250.

27. Record post-run static.

28. Close valve V-220.

29. Purge system.

B. Off Design Suction Characteristic.

1. Repeat steps 2 through 24 of baseline test except reduce flow by 10 percent (470 GPM: step 12, 700 GPM: step 15, 935 GPM: step 18).

2. Reduce rotor speed to 1120 RPM.

3. Repeat steps 12 through 24 of baseline test except reduce flow by 20 percent (415 GPM: step 12, 625 GPM: step 15, 830 GPM: step 18).

4. Reduce rotor speed to 1120 RPM.

5. Repeat steps 12 through 24 of baseline test except increase flow by 10 percent (570 GPM: step 12, 860 GPM: step 15, 1145 GPM: step 18).

6. Reduce rotor speed to 1120 RPM.

7. Repeat steps 12 through 24 of baseline test except increase flow by 20 percent (625 GPM: step 12, 935 GPM: step 15, 1250 GPM: step 18).

8. Repeat steps 25 through 29 of baseline test.

C. Cavitation

1. Repeat steps 2 through 19.

2. Throttle back flow with valve V-240 until head rise through impeller begins to drop sharply and continue until cavitation is induced.

3. Record pressure data.

4. Illuminate impeller leading edge using strobe light and vary frequency until impeller rotation is visually eliminated.

5. Make record of observation.

6. Record pressure data.

7. Reduce flow rate to 935 GPM by adjusting valves V-250.

8. Repeat steps 2 through 7 above.

9. Reduce flow rate to 830 GPM by adjusting valves V-250.

10. Repeat steps 2 through 7 above.

11. Reduce flow rate to 1145 GPM by adjusting valves V-250.

12. Repeat steps 2 through 7 above.

13. Reduce flow rate to 1250 GPM by adjusting valves V-250.

14. Repeat steps 2 through 7 above.

15. Repeat steps 25 through 29 of Baseline Test.

V. General Notes

A. Valves will be in the full closed position prior to all testing.

B. When repeating sections of baseline tests the recording of intermediate flow level data points is not necessary but will be repeated at the Test Engineers discretion.

C. At commencement of each days testing, water will be allowed to flow through system per the valves specified in that days baseline test. Flowing will continue until water becomes clear and free of rust particles. This water will then be dumped from the catch tank and not allowed to recirculate. Catch tank and external supply tank will then be refilled. During testing return pumps will be used to maintain constant level in catch tank and supply tank therefore maintaining constant supply head.

D. Each data recording will be accompanied by an input to the test log that will include date and time of recording, flow rate, pump speed, and test procedure step identification.

```
******************************
*                            *
*    HEADER NOMENCLATURE     *
*                            *
******************************
```

1. PROBE TYPE

P - PRESSURE
T - TEMPERATURE
A - ANGLE

2. PROBE MEASUREMENT

T - TOTAL
S - STATIC

3. FLOWPATH LOCATION

I - INLET FLANGE
V - VOLUTE
C - VANE CASCADE
A - ANNULUS
D - INDUCER/IMPELLER DISCHARGE
S - SEAL CAVITY

4. SPANWISE LOCATION INDEX

A, B, C ETC. - INNER TO OUTER WALL

5. CHORDWISE LOCATION OR WAKE PROBE NO.

1, 2, 3 ETC. - UPSTREAM TO DOWNSTREAM CHORDWISE LOCATION
OR - LEFT TO RIGHT WAKE ELEMENT NO.

6. CIRCUMFERENTIAL LOCATION

1, 2, 3 ETC.

EXAMPLE

```
1 2 3 4 5 6
| | | | | |
P S C A 2 1
```

P - PRESSURE
S - STATIC
C - VANE CHANNEL
A - INNER WALL
2 - NO. 2 CHORDWISE LOCATION
1 - NO. 1 CIRCUMFERENTIAL LOCATION

```
*******************************
*                             *
*    INSTRUMENTATION LIST     *
*                             *
*    HPFTP INLET H20 RIG      *
*                             *
*******************************
```

HEADER	PROBE TYPE	PROBE LOCATION	RANGE
PTIA	TOT PRESS KIEL RAKES	INLET FLANGE	0 - 30 PSIA
PTIB1	"	"	"
PTIB2	"	"	"
PTIB3	"	"	"
PTIB4	"	"	"
PTIC1	"	"	"
PTIC2	"	"	"
PTIC3	"	"	"
PTIC4	"	"	"
PTID1	"	"	"
PTID2	"	"	"
PTID3	"	"	"
PTID4	"	"	"
PSI1	STATIC PRESSURE	INLET FLANGE	"
PSI2	"	"	"
PSI3	"	"	"
PSI4	"	"	"
PSI5	"	INLET DIFFUSER	"
PSVA1	"	VOLUTE	"
PSVA2	"	"	"
PSVA3	"	"	"
PSVA4	"	"	"

TABLE 1

PSVA5	STATIC PRESSURE	VOLUTE	0 - 30 PSIA
PSVA6	"	"	"
PSVA7	"	"	"
PSVA8	"	"	"
PSVA9	"	"	"
PSVA10	"	"	"
PSVA11	"	"	"
PSVB1	"	"	"
PSVB2	"	"	"
PSVB3	"	"	"
PSVB4	"	"	"
PSVB5	"	"	"
PSVB6	"	"	"
PSVB7	"	"	"
PSVB8	"	"	"
PSVB9	"	"	"
PSVB10	"	"	"
PSVC1	"	"	"
PSVC2	"	"	"
PSVC3	"	"	"
PSVC4	"	"	"
PSVC5	"	"	"
PSVC6	"	"	"
PSVC7	"	"	"
PSVC8	"	"	"
PSVC9	"	"	"

TABLE 1

PTC	(1)	TOT PRESS, FLUID ANGLE WEDGE PROBE	VANE L.E.	0 - 30 PSIA
PTCA1		TOT PRESS KIEL PROBE	"	"
PTCA2		"	"	"
PTCA3		"	"	"
PTCA4		"	"	"
PTCA5		"	"	"
PTCB1		"	"	"
PTCB2		"	"	"
PTCB3		"	"	"
PTCB4		"	"	"
PTCB5		"	"	"
PTCC1		"	"	"
PTCC2		"	"	"
PTCC3		"	"	"
PTCC4		"	"	"
PTCC5		"	"	"
PSCA11		STATIC PRESSURE	VANE CHANNEL	"
PSCA12		"	"	"
PSCA13		"	"	"
PSCA14		"	"	"
PSCA15		"	"	"
PSCA21		"	"	"
PSCA22		"	"	"
PSCA23		"	"	"
PSCA24		"	"	"
PSCA25		"	"	"

TABLE 1

PSCA31	STATIC PRESSUE	VANE CHANNEL	0 - 30 PSIA
PSCA32	"	"	"
PSCA33	"	"	"
PSCA34	"	"	"
PSCA35	"	"	"
PSCA41	"	"	"
PSCA42	"	"	"
PSCA43	"	"	"
PSCA44	"	"	"
PSCA45	"	"	"
PSCB41	"	"	"
PSCB42	"	"	"
PSCB43	"	"	"
PSCB44	"	"	"
PSCB45	"	"	"
PTAA1 (1)	TOT PRESS, FLUID ANGLE THREE HOLE COBRA PROBE	IMPELLER L.E.	"
PTAA2	"	"	"
PTAA3	"	"	"
PTAA4	"	"	"
PTAB1	"	"	"
PTAB2	"	"	"
PTAB3	"	"	"
PTAB4	"	"	"
PTAC1	"	"	"
PTAC2	"	"	"
PTAC3	"	"	"

TABLE 1

PTAC4	(1)	TOT PRESS, FLUID ANGLE THREE HOLE COBRA PROBE	IMPELLER L.E.	0 - 30 PSIA
PTD1	(2)	TOT PRESS KIEL PROBE	IMPELLER DISCHARGE	0 - 130 PSIA
PTD2	(2)	"	"	"
PSS1	(2)	STATIC PRESSURE	IMPELLER SHROUD SEAL CAVITY	0 - 70 PSIA
PSS3	(2)	"	FORWARD SEAL CAVITY	0 - 50 PSIA
FLOW1		TURBINE FLOWMETER	RIG DISCH PRIMARY FLOW	0 - 1300 GPM
SPEED	(2)	TACHOMETER	MOTOR DRIVE	0 - 2800 RPM

(1) STATIC TEST ONLY

(2) DYNAMIC TEST ONLY

TABLE 1

****
*   *
*   INSTRUMENTATION LIST   *
*   *
*   HPOTP INLET H20 RIG   *
*   *
****

HEADER	PROBE TYPE	PROBE LOCATION	RANGE
PTIA1	TOT PRESS KIEL RAKES	INLET FLANGE	0 - 30 PSIA
PTIA2	"	"	"
PTIA3	"	"	"
PTIA4	"	"	"
PTIB1	"	"	"
PTIB2	"	"	"
PTIB3	"	"	"
PTIB4	"	"	"
PTIC1	"	"	"
PTIC2	"	"	"
PTIC3	"	"	"
PTIC4	"	"	"
PTID1	"	"	"
PTID2	"	"	"
PTID3	"	"	"
PTID4	"	"	"
PTIE1	"	"	"
PTIE2	"	"	"
PTIE3	"	"	"
PTIE4	"	"	"
PTIF	"	"	"
PSI1	STATIC PRESSURE	INLET FLANGE	"

TABLE 2

PSI2	STATIC PRESSURE	INLET FLANGE	0 - 30 PSIA
PSI3	"	"	"
PSI4	"	"	"
PSVA1	"	VOLUTE	"
PSVA2	"	"	"
PSVA3	"	"	"
PSVA4	"	"	"
PSVA5	"	"	"
PSVA6	"	"	"
PSVA7	"	"	"
PSVA8	"	"	"
PSVA9	"	"	"
PSVA10	"	"	"
PSVA11	"	"	"
PSVB1	"	"	"
PSVB2	"	"	"
PSVB3	"	"	"
PSVB4	"	"	"
PSVB5	"	"	"
PSVB6	"	"	"
PSVB7	"	"	"
PSVB8	"	"	"
PSVB9	"	"	"
PSVB10	"	"	"
PSVB11	"	"	"
PSVB12	"	"	"

TABLE 2

PSVB13		STATIC PRESSURE	VOLUTE	0 - 30 PSIA
PSVB14		"	"	"
PSVC1		"	"	"
PSVC2		"	"	"
PSVC3		"	"	"
PSVC4		"	"	"
PSVC5		"	"	"
PSVC6		"	"	"
PSVC7		"	"	"
PSVC8		"	"	"
PSVC9		"	"	"
PSVC10		"	"	"
PSVC11		"	"	"
PTC	(1)	TOT PRESS, FLUID ANGLE WEDGE PROBE	VANE L.E.	"
PTCA1		TOT PRESS KIEL PROBE	"	"
PTCA2		"	"	"
PTCA3		"	"	"
PTCA4		"	"	"
PTCB1		"	"	"
PTCB2		"	"	"
PTCB3		"	"	"
PTCB4		"	"	"
PTCC1		"	"	"
PTCC2		"	"	"
PTCC3		"	"	"
PTCC4		"	"	"

TABLE 2

PSC11	STATIC PRESSURE	VANE SUCTION SURACE	0 - 30 PSIA
PSC12	"	"	"
PSC13	"	"	"
PSC14	"	"	"
PSC21	"	"	"
PSC22	"	"	"
PSC23	"	"	"
PSC24	"	"	"
PSC31	"	"	"
PSC32	"	"	"
PSC33	"	"	"
PSC34	"	"	"
PSC41	"	"	"
PSC42	"	"	"
PSC43	"	"	"
PSC44	"	"	"
PSCA11	STATIC PRESSURE	VANE CHANNEL	"
PSCA12	"	"	"
PSCA13	"	"	"
PSCA14	"	"	"
PSCA21	"	"	"
PSCA22	"	"	"
PSCA23	"	"	"
PSCA24	"	"	"
PSCA31	"	"	"
PSCA32	"	"	"
PSCA33	"	"	"

PSCA34	STATIC PRESSURE	VANE CHANNEL	0 - 30 PSIA
PSCB11	"	"	"
PSCB12	"	"	"
PSCB13	"	"	"
PSCB14	"	"	"
PSCB21	"	"	"
PSCB22	"	"	"
PSCB23	"	"	"
PSCB24	"	"	"
PSCB31	"	"	"
PSCB32	"	"	"
PSCB33	"	"	"
PSCB34	"	"	"
PTC11	TOT PRESS WAKE RAKE	VANE T.E.	"
PTC21	"	"	"
PTC31	"	"	"
PTC41	"	"	"
PTC51	"	"	"
PTC61	"	"	"
PTC71	"	"	"
PTC81	"	"	"
PTC91	"	"	"
PTC101	"	"	"
PTC12	"	"	"
PTC22	"	"	"
PTC32	"	"	"
PTC42	"	"	"

TABLE 2

PTC52	TOT PRESS WAKE RAKE	VANE T.E.	0 - 30 PSIA
PTC62	"	"	"
PTC72	"	"	"
PTC82	"	"	"
PTC92	"	"	"
PTC102	"	"	"
PSAA11	STATIC PRESSURE	INLET ANNULUS	"
PSAA12	"	"	"
PSAA13	"	"	"
PSAA14	"	"	"
PSAA21	"	"	"
PSAA22	"	"	"
PSAA23	"	"	"
PSAA24	"	"	"
PSAA31	"	"	"
PSAA32	"	"	"
PSAA33	"	"	"
PSAA34	"	"	"
PSAA41	"	"	"
PSAA42	"	"	"
PSAA43	"	"	"
PSAA44	"	"	"
PSAA51	"	"	"
PSAA52	"	"	"
PSAA53	"	"	"
PSAA54	"	"	"
PSAB11	"	"	"

TABLE 2

PSAB12		STATIC PRESSURE	INLET ANNULUS	0 - 30 PSIA
PSAB13		"	"	"
PSAB14		"	"	"
PSAB21		"	"	"
PSAB22		"	"	"
PSAB23		"	"	"
PSAB24		"	"	"
PSAB31		"	"	"
PSAB32		"	"	"
PSAB33		"	"	"
PSAB34		"	"	"
PSAB41		"	"	"
PSAB42		"	"	"
PSAB43		"	"	"
PSAB44		"	"	"
PTAA1	(1)	TOT PRESS, FLUID ANGLE THREE HOLE COBRA PROBE	INDUCER L.E.	"
PTAA2		"		
PTAA3		"	"	"
PTAA4		"	"	"
PTAB1		"	"	"
PTAB2		"	"	"
PTAB3		"	"	"
PTAB4		"	"	"
PTAC1		"	"	"
PTAC2		"	"	"
PTAC3		"	"	"
PTAC4		"	"	"

TABLE 2

PTDA1	(2)	TOT PRESS KIEL RAKES	INDUCER DICHARGE	0 - 70 PSIA
PTDA2		"	"	"
PTDA3		"	"	"
PTDA4		"	"	"
PTDB1		"	"	"
PTDB2		"	"	"
PTDB3		"	"	"
PTDB4		"	"	"
PTDC1		"	"	"
PTDC2		"	"	"
PTDC3		"	"	"
PTDC4		"	"	"
FLOW1		TURBINE FLOWMETER	RIG DISCH PRIMARY FLOW	0 - 900 GPM
FLOW2		"	BYPASS FLOW	"
SPEED	(2)	TACHOMETER	MOTOR DRIVE	0 - 6000 RPM

(1) STATIC TEST ONLY

(2) DYNAMIC TEST ONLY

ON STAND DATA CALCULATIONS

HPFTP RIG

$PTI = \frac{\Sigma PTI}{NO.\ OF\ PROBES}$	AVG TOTAL INLET PRESSURE ΣPTIA THRU PTID4 13 PROBES (MINUS DELETIONS)
$PSI = \frac{\Sigma PSI}{NO.\ OF\ PROBES}$	AVG STATIC INLET PRESSURE ΣPSI1 THRU PSI4 4 PROBES (MINUS DELETIONS)
$PTCK = \frac{\Sigma PTC}{NO.\ OF\ PROBES}$	AVG TOT PRESS VANE L.E. USING KIEL PROBES ΣPTCA1 THRU PTCC5 15 PROBES (MINUS DELETIONS)
$PTA = \frac{\Sigma PTA}{NO.\ OF\ PROBES}$	AVG TOT PRESS ANNULUS DISCHARGE ΣPTAA1 THRU PTAC4 12 PROBES (MINUS DELETIONS)
$PTD = \frac{\Sigma PTD}{NO.\ OF\ PROBES}$	AVG TOT PRESS IMPELLER DISCHARGE ΣPTD1 AND PTD2 2 PROBES (MINUS DELETIONS)
DPTVK = PTI - PTCK	VOLUTE PRESS LOSS USING KIEL PROBES
DPTVW = PTI - PTC	VOLUTE PRESS LOSS USING WEDGE PROBE
DPTCK = PTCK - PTA	VANE AND ANNULUS PRESS LOSS USING KIEL PROBES
DPTCW = PTC - PTA	VANE AND ANNULUS PRESS LOSS USING WEDGE PROBE
DPT = PTI - PTA	OVERALL LOSS FROM INLET TO ANNULUS DISCHARGE
NPSPI = PTI - PVAP	NET POSITIVE SUCTION PRESS AT INLET
NPSPA = PTA - PVAP	NET POSITIVE SUCTION PRESS AT ANNULUS DISCHARGE
$NSSI = \frac{N*(Q)**1/2}{(NPSPI*144/RHO)**3/4}$	SUCTION SPECIFIC SPEED AT INLET
$NSSA = \frac{N*(Q)**1/2}{(NPSPA*144/RHO)**3/4}$	SUCTION SPECIFIC SPEED AT ANNULUS DISCHARGE
DPD = PTD - PTA	TOTAL PRESS RISE ACROSS IMPELLER

TABLE 3

ON STAND DATA CALCULATIONS

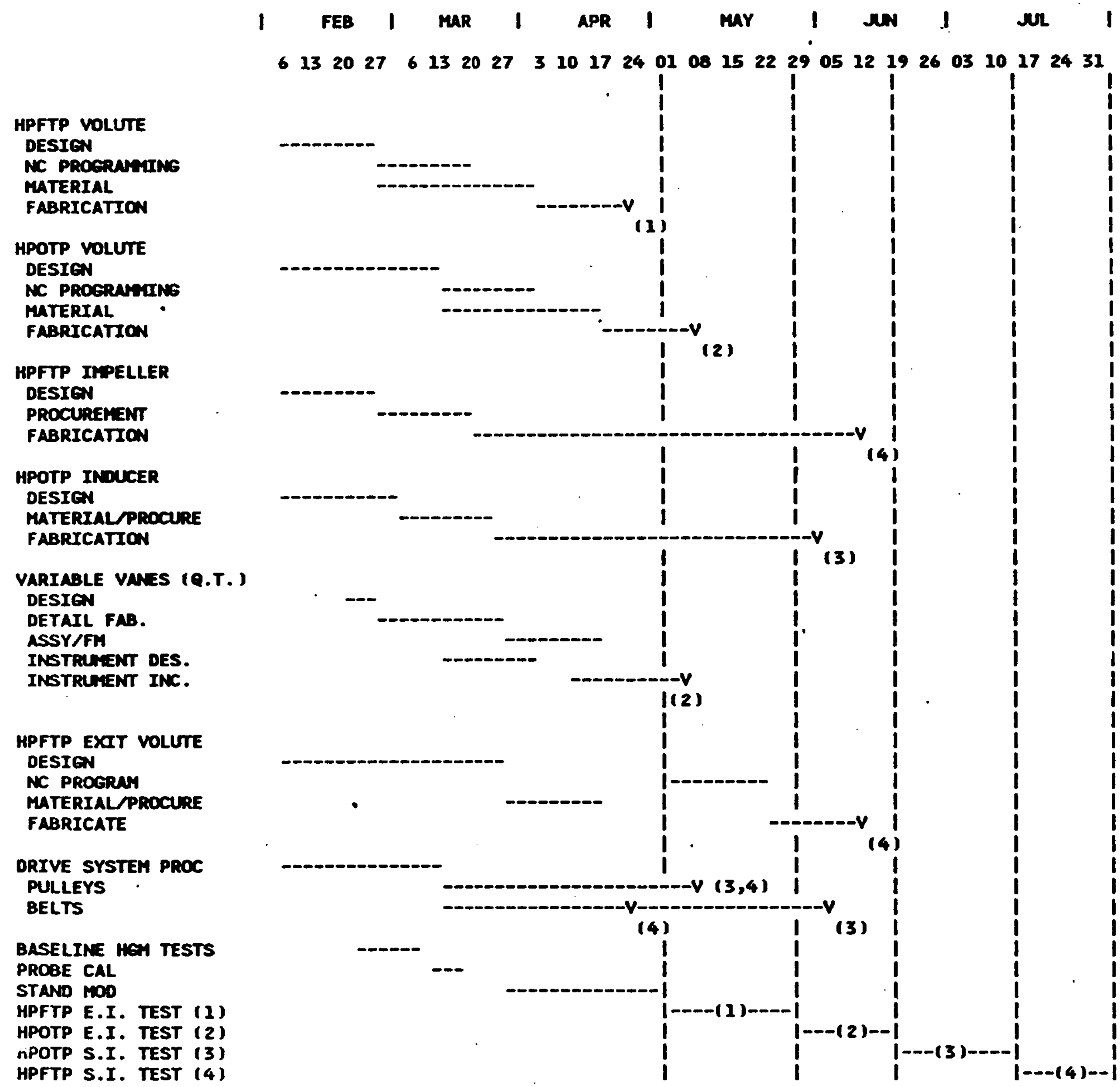
HPOTP RIG

$PTI = \frac{\Sigma PTI}{\text{NO. OF PROBES}}$	AVG TOTAL INLET PRESSURE ΣPTIA1 THRU PTIF 21 PROBES (MINUS DELETIONS)
$PSI = \frac{\Sigma PSI}{\text{NO. OF PROBES}}$	AVG STATIC INLET PRESSURE ΣPSI1 THRU PSI4 4 PROBES (MINUS DELETIONS)
$PTCK = \frac{\Sigma PTC}{\text{NO. OF PROBES}}$	AVG TOT PRESS VANE L.E. USING KIEL PROBES ΣPTCA1 THRU PTCC4 12 PROBES (MINUS DELETIONS)
$PTCW = \frac{\Sigma PTC1}{\text{NO. OF PROBES}}$	AVG TOT PRESS VANE T.E. ΣPTC11 THRU PTC102 20 PROBES (MINUS DELETIONS)
$PTCWL = \frac{\Sigma PTC1}{\text{NO. OF PROBES}}$	AVG TOT PRESS VANE T.E. LEFT SIDE ΣPTC11 THRU PTC101 10 PROBES (MINUS DELETIONS)
$PTCWR = \frac{\Sigma PTC2}{\text{NO. OF PROBES}}$	AVG TOT PRESS VANE T.E. RIGHT SIDE ΣPTCA1 THRU PTC102 10 PROBES (MINUS DELETIONS)
$PTA = \frac{\Sigma PTA}{\text{NO. OF PROBES}}$	AVG TOT PRESS ANNULUS DISCHARGE ΣPTAA1 THRU PTAC4 12 PROBES (MINUS DELETIONS)
$PTD = \frac{\Sigma PTD}{\text{NO. OF PROBES}}$	AVG TOT PRESS INDUCER DISCHARGE ΣPTDA1 AND PTDC4 12 PROBES (MINUS DELETIONS)
DPTVK = PTI - PTCK	VOLUTE PRESS LOSS USING KIEL PROBES
DPTVW = PTI - PTC	VOLUTE PRESS LOSS USING WEDGE PROBE
DPTCK = PTCK - PTCW	VANE PRESS LOSS USING KIEL PROBES
DPTCW = PTC - PTCW	VANE PRESS LOSS USING WEDGE PROBE
DPTA = PTCW - PTA	ANNULUS PRESSURE LOSS
DPT = PTI - PTA	OVERALL LOSS FROM INLET TO ANNULUS DISCHARGE

TABLE 4

NPSPI = PTI - PVAP	NET POSITIVE SUCTION PRESS AT INLET
NPSPA = PTA - PVAP	NET POSITIVE SUCTION PRESS AT ANNULUS DISCHARGE
NSSI = $\frac{N*(Q)**1/2}{(NPSPI*144/RHO)**3/4}$	SUCTION SPECIFIC SPEED AT INLET
NSSA = $\frac{N*(Q)**1/2}{(NPSPA*144/RHO)**3/4}$	SUCTION SPECIFIC SPEED AT ANNULUS DISCHARGE
DPD = PTD - PTA	TOTAL PRESS RISE ACROSS IMPELLER

TABLE 4 (cont.)


FEB
MAR
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MAY
JUN
JUL
6 13 20 27 6 13 20 27 3 10 17 24 01 08 15 22 29 05 12 19 26 03 10 17 24 31
HPFTP VOLUTE
DESIGN
NC PROGRAMMING
MATERIAL
FABRICATION
(1)
HPOTP VOLUTE
DESIGN
NC PROGRAMMING
MATERIAL
FABRICATION
(2)
HPFTP IMPELLER
DESIGN
PROCUREMENT
FABRICATION
(4)
HPOTP INDUCER
DESIGN
MATERIAL/PROCURE
FABRICATION
(3)
VARIABLE VANES (Q.T.)
DESIGN
DETAIL FAB.
ASSY/FM
INSTRUMENT DES.
INSTRUMENT INC.
(2)
HPFTP EXIT VOLUTE
DESIGN
NC PROGRAM
MATERIAL/PROCURE
FABRICATE
(4)
DRIVE SYSTEM PROC
PULLEYS
(3,4)
BELTS
(4)
(3)
BASELINE HGM TESTS
PROBE CAL
STAND MOD
HPFTP E.I. TEST (1)
HPOTP E.I. TEST (2)
nPOTP S.I. TEST (3)
HPFTP S.I. TEST (4)
(1)
(2)
(3)
(4)

FIGURE 1

HPFTP INLET H_2O RIG INSTRUMENTATION

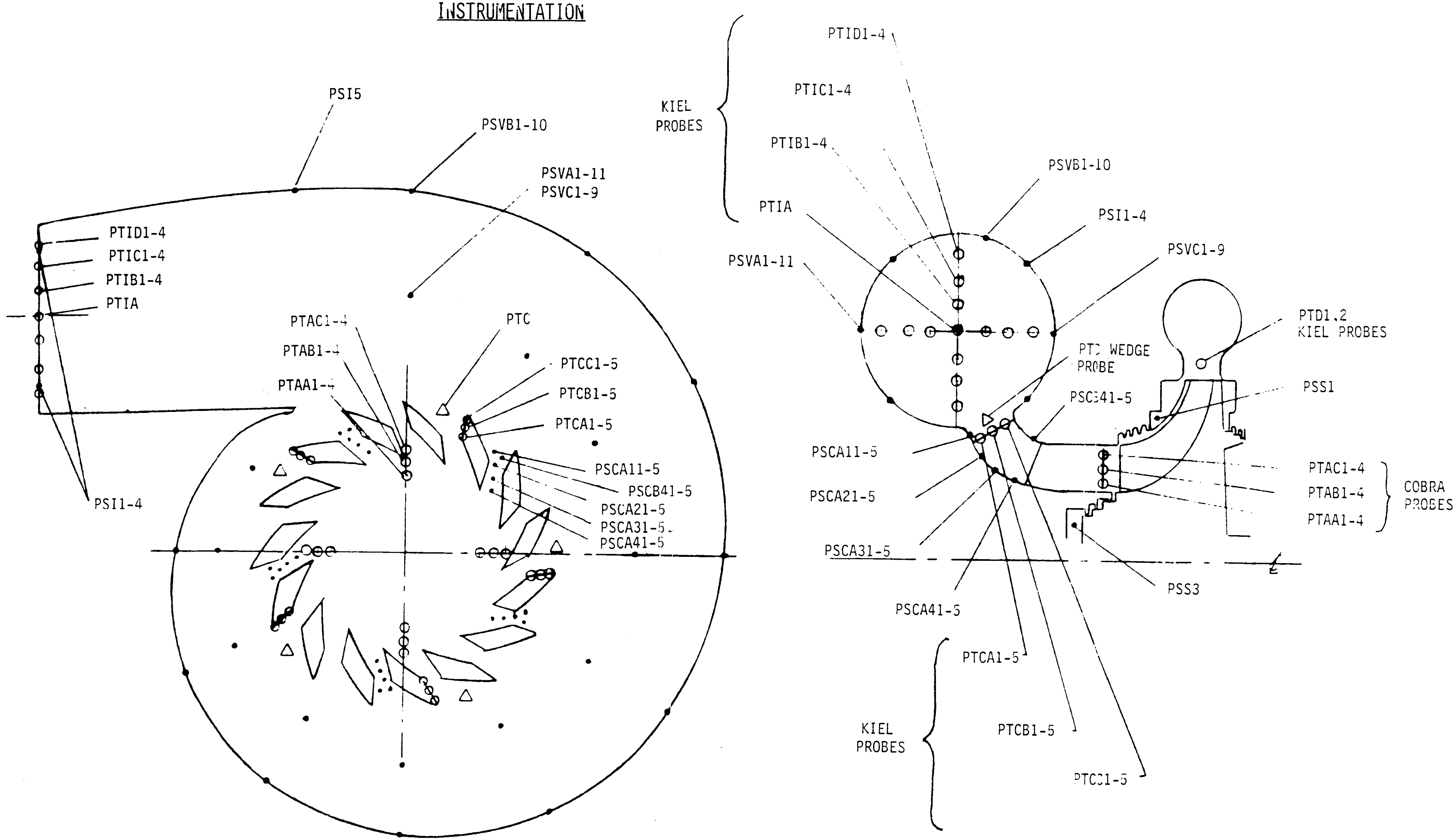

FIGURE 2

HPOTP INLET H_2O RIG
INSTRUMENTATION

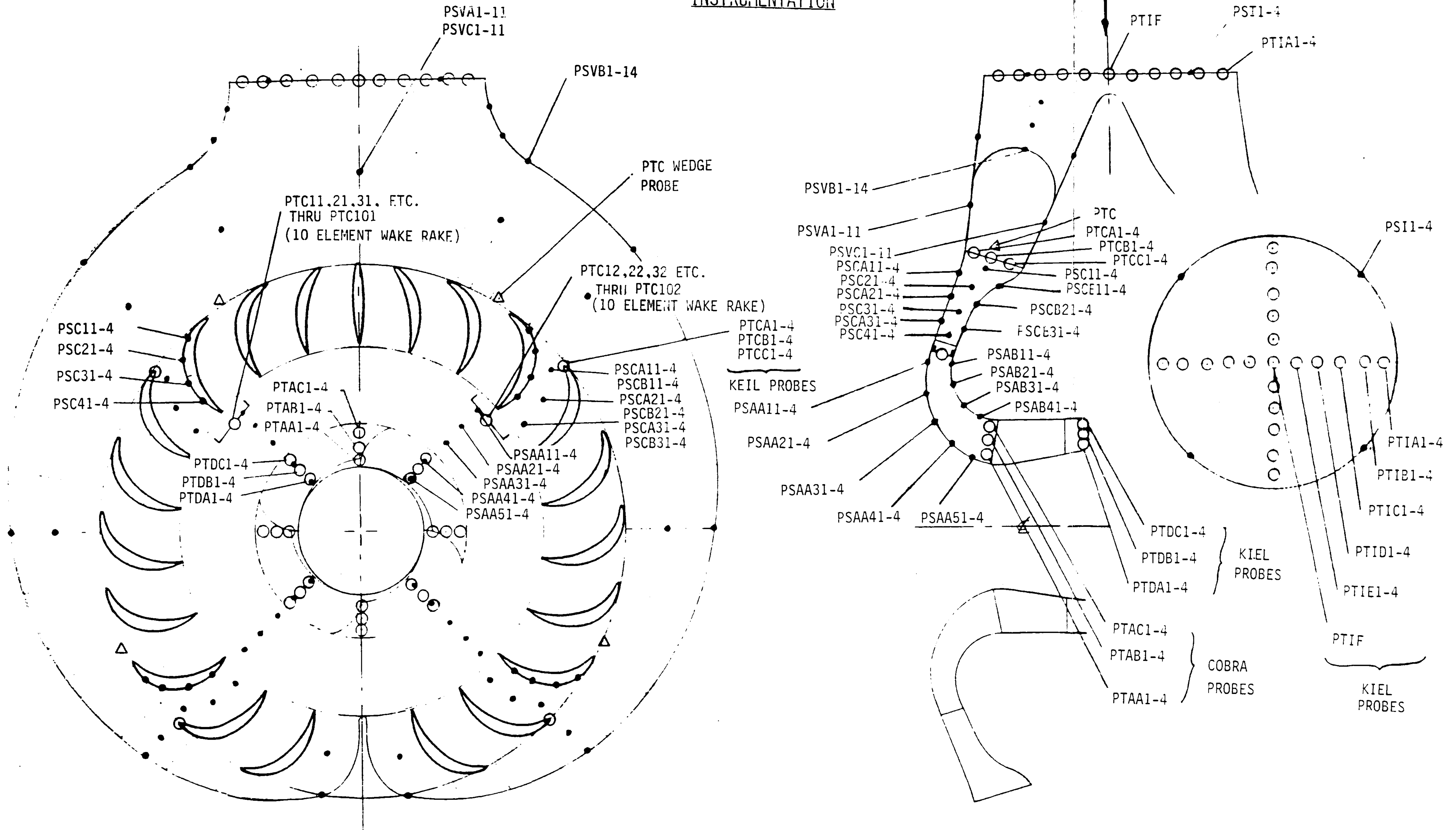

FIGURE 3